Genetics and Evolution IB 201 06- Lecture 6

First Cells and the Universal Tree of Life

Do all of you agree on the definition of life given in the previous notes? Earth's early environment (hot, rocky!) is somewhat difficult to reconstrct in detail, due to the age and the many cataclysmic events that have occurred on Earth over the last 4 billion years. The earliest polymers (long-chained molecules) of nucleotides and polypeptides probably came into being from the most basic and common elements (CHON- PS) available on earliest Earth. Were the first self-replicating molecules RNA? Was the Earth's early atmosphere a reducing atmosphere (CH_4- methane, NH_3- ammonia) or was it was oxidizing (CO_2, O_2)?

We are left to consider: What were the characteristics of the first cells?

Because there is no direct evidence in the form of fossils of the earliest cells, evidence must be gathered from several disciplines to infer what earliest cells were like.

1. **PALEONTOLOGY** provides us with fossil evidence of early cells, which date back to about 3.5 billion years. Obviously, this means that the first cells came into being much earlier than this. These earliest fossil cells found in the **Apex chert** rock formation in Western Australia are thus far not definitively identified, but William Schopf (Cradle of Life), renowned paleontologist of early life fossils, believes they are **cyanobacteria** (photosynthesizing bacteria). However, because there are no fossils of the very first single cells, preceding cyanobacteria, paleontology can only take us near the answer of the first cells.
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2. **MOLECULAR PHYLOGENETICS** provides insights using a different approach. Using the methods of DNA sequencing and phylogenetic analysis (via parsimony and maximum likelihood) to obtain the "tree of life", it is possible to use the tree to map traits onto the "tree of life" to see how they might have evolved. One can use the tree to infer what the earliest common ancestor of all cells must have looked like.

I. The Universal Tree of Life

A. The role of Carl Woese

B. What is the new Domain of life discovered by Woese?

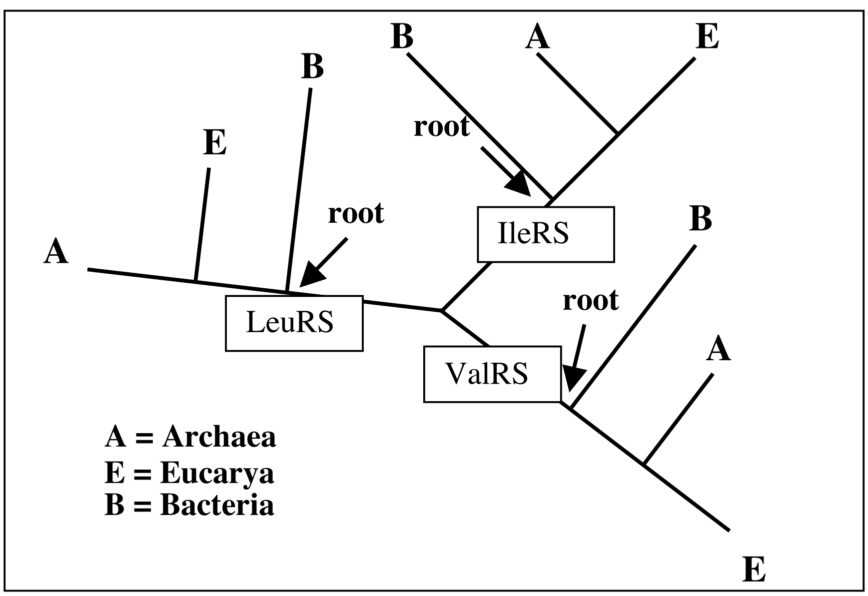
C. What was the pattern of the Tree of Life before Woese/ after Woese

D. Rooting the tree of life

- **Why is this difficult?** (hint: think ***outgroup***)

- **How can multi-gene families help to root the tree?**

Example: aminoacyl-tRNA synthetase gene family
[*IleRS* (Isoleucine tRNA synthetase) gene, *ValRS* (ValineRS) gene and *LeuRS* (LeucineRS) = three members of the family]



II. Characteristics of each Domain

- **Eucarya—**cells with nuclei, organelles
- **Bacteria—**no nuclei, no organelles
- **Archaea—**like Bacteria and like Eucarya (a mix of traits)

  -- Like Bacteria: no nuclei; no organelles

  --Like Eucarya: histone proteins associated with DNA; introns in some genes

  --Unique to Archaea: have hydrocarbons not found in Eucarya or Bacteria, some species can survive at extraordinarily high temperatures, simpler system for translation, transcription and genome replication than eukaryotic cells

Woese suggests that cellular organization of the 3 Domains of life each evolved independently.

That is, there is no single ancestral cell type that goes back to a single common ancestor.

III. Horizontal (Lateral) Gene Transfer (HGT)

Definition: transfer of genetic information between species and individuals rather than from parent to offspring (vertical transfer).

From DNA sequences of many organisms, the Universal Tree of Life shows that there was a lot of movement of genes from one taxon to another (lateral gene transfer).

- **What are two of the more famous examples of this sharing of DNA among early cells?**

Woese believes that HGT dominated early on in the evolution of cell compartmentalization, but later became almost infrequent as cells became integrated units rather than modular units that acted somewhat independently.

- **Is HGT common or is it unusual in Bacteria?** (See F&H p. 647, Box 16.2)

HGT seems to be the explanation for why different genes seem to root the Universal Tree on different branches. See Fig. 16.22

IV. First Cells

Several lines of evidence suggest that the first-celled organisms looked like or even were bacterial in form. Evidence comes from:

- **The Universal Tree of Life** based on many phylogenetic analyses of different DNA sequences and application of the parsimony criterion suggest that the common ancestor of the tree was a single-celled organism, likely to have been bacterial-like; it probably contained DNA and/or RNA. It also suggests that some of its genes came from lateral transfer of other cells or other genes.

- **Geology and Paleontology** provide evidence that the first cells were bacterial-like, if not actually **cyanobacteria**. Evidence from Iron-band formations and stromatolites indicate the origin (first divergence on the tree) of cellular life was probably between 3.9 and 3.5 billion years ago. The time estimates are not accepted by all scientists in the field.

- **Bacteria and Archaea have not changed** much since their early evolution, and any change has been slow and gradual.

- **Eukarya, however, underwent major change** and radiation of diversity.

V. Fossils as estimates of divergence times of the Universal Tree

The **Apex Chert fossils** put a minimum age of the first cells at 3.5 billion years ago, but they are too advanced to be close to life's beginnings. "Living systems arose during the first billion years of Earth's existence, but just when is an open question."(Schopf, 1999, p. 166).

- **Why might no living cells have evolved during the first 500 my of Earth's history?**

The oldest known **fossil eukaryotes** are 1.85-2.1 billion years old, collected in Michigan and thought to be algae.

- **How old is the oldest known fossil eukaryote? What is the fossil?**

Scenario for early environment of Earth

Earth's environment had only **trace quantities of oxygen until about 2.0 billion years ago**, when cyanobacterial oxygen from photosynthesis was allowed to accumulate in the atmosphere. Before that it reacted chemically in the oceans with ferrous iron from the earth's hot interior to produce ferric iron oxides which precipitated out of solution to form the **banded-iron formations**. These rocks contain evidence of photosynthesizing cyanobacteria. **Stromatolites** (microbial mats, rich in cyanobacteria) also provide evidence of early phyotsynthetic life—the oldest stromatolites are found in Western Australia (3.45 billion years old). Today's living stromatolitic beds look similar to the ancient fossilized beds—i.e., they have not changed much. Thus, they can tell us what the early environment was like but not much about the evolution of cells.

References

Text: F&H pp. 636-657.

Schopf, J. W. 1999. *Cradle of Life*. Princeton University Press, Princeton, New Jersey. (Chaps. 4-9).

Woese, C. R. 2002. On the evolutionof the cells. *Proceedings of the National Academy of Sciences USA* 99: 8742-8747.